Groves Mechanism vs Profit Sharing for Corporate Budgeting – an Experimental Analysis with Preplay Communication*

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Third Draft, January 2006

Abstract

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1 Introduction

Traditional budgeting mechanisms provide incentives for subordinate managers to misrepresent their productivity and to build slack into budgets (e.g. Jensen (2003)). To avoid such misrepresentations, analytical research has proposed a number of truth inducing compensation schemes (e.g. Weitzman (1976), Reichelstein and Osband (1984), Osband and Reichelstein (1985)). Among these schemes, particularly the one developed by Vickrey (1964), Clarke (1971) and Groves (1973), the so-called Groves mechanism, and its incentive properties have generated substantial interest among researchers.[1] Under this mechanism, a manager's compensation depends on his own division's actual profit and the reported profits of all other divisions, and analytical research has shown that this is generally truth inducing. Despite its theoretically desirable properties, however, the Groves mechanism is not observed in compensation practice.

Analytical studies have particularly criticized two characteristics of the Groves mechanism: First, division managers can benefit by coordinating their messages and manipulating their reported profits upwards (Loeb and Magat (1978), Banker and Datar (1992)). Second, using the Groves mechanism is not optimal if a hidden action problem is added to the hidden information problem (Kanodia (1993), Hofmann and Pfeiffer (2003)).[2]

The experimental study presented in this paper analyzes the first of these two points. Indeed, it can be shown that under certain specifications of the general class of control mechanisms defined in Groves and Loeb (1979) division managers can benefit by coordinating their reports and manipulating their reported productivities upwards.[3] However, if all division managers are individually rational, this strategy does not represent an equilibrium in the budget game because *given* the other managers' reports it is optimal for every manager to report truthfully (Loeb and Magat (1978), Budde, Göx and Luhmer (1998)).

We will not address the second of the points above in this paper as the experimental findings on the first point, i.e. whether the Groves mechanism induces truth telling or

[1]See e.g. Green and Laffont (1977), Loeb and Magat (1978), Holmström (1979), Cohen and Loeb (1984). Groves (1976) and Groves and Loeb (1979) adapted this mechanism to budgeting processes in divisionalized firms.

[2]See also Banker and Datar (1992) for the potential nonoptimality of the Groves mechanism with precontract private information.

[3]One of these specifications is usually used in experimental studies of the Groves mechanism. Note however, that one can easily find specifications for which managers could benefit by coordinating their reports and *understating* their profit functions.

provides incentives to collude in reality, are so far inconclusive. Thus, it is still unclear whether this mechanism achieves its basic task of inducing truthful reports at all.

The number of experimental studies on the Groves mechanism is surprisingly small. However, existing studies show that (i) the Groves mechanism generally does not lead to truthful reporting behavior, but that (ii) these deviations from truth telling cannot be traced back to collusive behavior of the participants (Waller and Bishop (1990), Chow, Hirst and Shields (1994), Chow, Hwang and Liao (2000)). Moreover, when compared to other (truth inducing) compensation schemes the Groves mechanism turns out to be superior in most cases: Waller and Bishop (1990) find that the Groves mechanism is more effective in inducing truthful reporting behavior than a division profit scheme. The results of Chow, Hirst and Shields (1994) show more truthful reports under the Groves mechanism than under a division profit scheme and a Weitzman scheme. Finally, Chow, Hwang and Liao (2000) find that both the frequency and the amount of misrepresentation are lower under the Groves mechanism than under an Osband-Reichelstein scheme, but larger than under a division profit scheme with resource allocation and audits from a third player.

These experimental results seem surprising at a first glance as they still support an incentive mechanism not observed in practice. However, none of the mechanisms tested against the Groves mechanism is designed for a resource allocation context where multiple divisions in a firm compete for the same resources. Analytically, it can be shown that these mechanisms do not provide incentives for truth telling in such situations (Loeb and Magat (1978), Waller (1994)). In contrast, this paper compares the Groves mechanism to a profit sharing scheme that links the manager's compensation to overall firm profit. As for the Groves mechanism, truthful reporting behavior indeed represents an equilibrium for the players under this incentive scheme. However, while truth telling is the unique dominant strategy equilibrium under the Groves mechanism, it forms a Nash equilibrium under profit sharing but this equilibrium may not be unique (Loeb and Magat (1978)). Yet, the fact that truth telling is not the unique equilibrium under profit sharing does not pose a problem from headquarters' perspective unless the existence of multiple equilibria leads to inefficient resource allocation due to coordination failures. This paper explores how the theoretical differences between these two incentive schemes translate into real behavior.

Moreover, this paper analyzes the effects of cheap talk on both incentive mechanisms in order to be closer to corporate reality with its various communication possibilities than the complete anonymity conditions usually characteristic for experimental economics. Cheap talk is implemented by giving the participants in some treatments the possibility of anonymous preplay communication. As in reality, the participants in our experiment could not make binding agreements during the communication.

Prior experiments have shown that communication can have substantial effects on experimental outcome even if it should be irrelevant from a theoretical perspective. Basically, there are two main effects of communication: First, in social dilemma experiments, decreasing social distance between participants via communication increases cooperation.[4] Second, in coordination problems communication helps to overcome coordination failures and usually increases equilibrium play (e.g. Cooper, DeJong, Forsythe and Ross (1989, 1994)).[5] In these model structures, cheap talk can already matter from a theoretical perspective (e.g. Farrell (1987), Farrell and Rabin (1996)). Thus, the effects of communication on both incentive schemes could be quite different: With respect to profit sharing, communication can improve the coordination of the managers, and this is beneficial from headquarters' perspective. In contrast, with regard to the Groves mechanism, the communication possibility should not matter from a standard theoretical perspective, but prior experimental evidence suggests that it could matter from an empirical point of view as it raises cooperation. This would be detrimental for headquarters as it implies larger compensation costs.

Finally, we also conducted a Groves treatment with communication and a positive auditing probability in every round to account for the possibility of internal audits in reality and to reduce the probability that deviations from truth telling are due to incomplete understanding of the dominant strategy. Prior experiments have shown that probabilistic audits are effective in inducing truthful reporting behavior (Chow, Hirst and Shields (1995), Chow, Hwang and Liao (2000)).

Our principal findings are: Consistent with results of prior experimental studies we find that all Groves treatments lead to significant deviations from truthful reporting behavior. However, while the misrepresentation of productivities in the treatment without communication can be traced back to either incomplete understanding

[4]For the effects of communication on social dilemma situations see e.g. Dawes, McTavish and Shaklee (1977), Isaac, McCue and Plott (1985), Isaac and Walker (1988), Kerr and Kaufman-Gilliland (1994). See also Sally (1995) for a meta-analysis of social dilemma experiments and the effects of communication. Social distance can be also decreased by identifying game partners via photos or direct face-to-face encounters without communication, see e.g. Fox and Guyer (1978), Bohnet and Frey (1999a,b), Andreoni and Petrie (2004).

[5]However, communication generally does not lead to full efficiency.

of the Groves mechanism or social preferences, misrepresentation in the treatment with communication is due to coordinated collusive behavior of the participants. Average misrepresentation in the communication treatment more than triples relative to the noncommunication treatment. Moreover, the deviations from truth telling in the communication treatment increase during the first rounds and remain stable during the rest of the game. We do not observe any end-game effect. Thus, communication leads to stable collusion strategies of the participants in our experimental setting. Adding a positive auditing probability to the communication treatment conditions reduces average misrepresentation to a level slightly above that in the noncommunication treatment and increases the frequency of truthful reports. However, the positive auditing probability does not eliminate the stability of the participants' collusion strategies. Again, we do not observe any end-game effect. In contrast, both profit sharing treatments lead to significantly lower deviations from truth telling than every Groves treatment. In the treatment without communication however, coordination failures are very likely to occur. In only 30% of the cases an equilibrium is hit by the participants. As predicted, the communication possibility strongly increases equilibrium play by the participants to 75% of the cases. Finally, when we examine the effects of misrepresentation and coordination failures on headquarters' net earnings, we find that earnings are larger in both profit sharing treatments than in all Groves treatments.

Thus, although the Groves mechanism is superior from a theoretical perspective, the profit sharing scheme turns out to be superior in our experimental setting. This is essentially due to the effects of the communication possibility on both incentive schemes: While improved coordination under the profit sharing scheme is beneficial for headquarters, the participants' stable collusion strategies in the Groves treatments lead to inefficient resource allocation and particularly to larger compensation costs. We argue that with respect to corporate reality with its various communication possibilities our results contribute to explain why the Groves mechanism is not used as an incentive scheme in budgeting processes in reality. While it is collusion proof from a theoretical perspective, it is not when implemented in practice.

The remainder of the paper is structured as follows: Section 2 briefly presents the model which was implemented in the experiment in a discrete version. Section 3 describes the experimental design and derives the hypotheses. The experimental results are presented in section 4, and section 5 concludes.

2 The model

In a finitely repeated game headquarters of a decentralized firm has to allocate $\bar{x}$ units of a scarce resource among two divisions.[6] Division i's profit function $\widetilde{\pi}_i(x_i)$ is given by:

$$\widetilde{\pi}_i(x_i) = (p_i^0 - \frac{1}{2}bx_i) \cdot x_i - x_i + \widetilde{\varepsilon}_i \quad \text{for} \quad i = 1,2 \quad \text{with } b > 0 \tag{1}$$

where x_i is the number of resource units allocated to division i and $\widetilde{\varepsilon}_i$ is a division specific noise term with mean 0. Noise terms are uncorrelated across divisions and are distributed such that the divisions' productivity parameters p_i^0 cannot be inferred from the realization of $\widetilde{\pi}_i(x_i)$.

We further assume that there are different levels of information asymmetry in the firm and that headquarters generally has inferior information about the divisions' productivities. In the model, this is reflected by the assumption that b is common knowledge and identical for both divisions and in all periods, but the divisions' productivity parameters p_i^0 are uncertain for both headquarters and the division managers before every period starts. However, it is known to the division managers ex ante that for both divisions p_i^0 is a random variable on the interval $[p_{\min}^0, p_{\max}^0]$. At the beginning of each period every division manager learns the realization of his division's productivity parameter for this period. The realization is independent of previous realizations and independent of the other division's parameter. With respect to headquarters' information we assume that there already exists a potential information asymmetry between headquarters and division managers ex ante. That means, not only does headquarters not know the actual productivity parameters of the current period but headquarters also has inferior information about the potential values of the productivity parameters.[7] More precisely, from headquarters' perspective the divisions' productivity parameters are random variables on the interval $[p_{\min}^0 - \Delta, p_{\max}^0 + \Delta]$ where $p_{min}^0 - \Delta - b\bar{x} \geq 1$ and $p_{\min}^0 - \Delta > p_{\max}^0 + \Delta - b\bar{x}$. The first constraint reflects the fact that although

[6]In the experiment, participants played ten rounds of this game. However, this is irrelevant for the (standard) theoretical solution as the multiperiod case is solved by backward induction. Therefore, we will only analyze the one shot game in the following.

[7]This assumption can be justified if operating executives have superior knowledge about the productivities of other operational units compared to central accounting or financing departments. Technically, this assumption is necessary to induce multiple pareto efficient Nash equilibria in the profit sharing treatments. With $\Delta = 0$ the only pareto efficient equilibrium in pure strategies would be truth telling. This ex ante information asymmetry thus prevents participants' focussing on this equilibrium during the experiment. For pareto efficiency as a natural focal point see e.g. Schelling (1966), Appendix C, Harsanyi and Selten (1988), chap. 3, also Cooper, DeJong, Forsythe and Ross (1990) and VanHuyck, Battalio and Beil (1990) for experimental results.

marginal revenue decreases linearly in x_i, every division could productively employ all available resource units. The second constraint however implies that it is never optimal to allocate all resource units to only one of the two divisions. Thus, in order to optimally allocate the resource units among the two divisions headquarters needs truthful information from the division managers about p_i^0.

After the managers' reports headquarters allocates the resource units among the two divisions. Therefore, it solves

$$\begin{aligned}\underset{\hat{x}_i,\hat{x}_j}{Max}\ E(\widetilde{\pi}) &= E(\widetilde{\pi}_i)+E(\widetilde{\pi}_j)=(\hat{p}_i^0-1)\hat{x}_i-\frac{1}{2}b\hat{x}_i^2+(\hat{p}_j^0-1)\hat{x}_j-\frac{1}{2}b\hat{x}_j^2 \\ s.t.\ \ \hat{x}_i+\hat{x}_j &= \bar{x}\end{aligned} \tag{2}$$

where $\hat{p}_i^0$ and $\hat{p}_j^0$ represent the reported productivity parameters and $\widehat{x}_i$ and $\widehat{x}_j$ are the resource units allocated to the two divisions upon their reports. Thus, headquarters' decision rule is the maximization of *reported* firm profit. This maximizes *actual* firm profit if truth telling is optimal for the division managers given this allocation scheme. Solving (2) yields:

$$\hat{x}_i=\frac{\hat{p}_i^0-\hat{p}_j^0+b\bar{x}}{2b} \tag{3a}$$

and

$$\hat{x}_j=\frac{\hat{p}_j^0-\hat{p}_i^0+b\bar{x}}{2b} \tag{3b}$$

Every manager maximizes his expected utility in this model if he maximizes the expected value of his compensation. Let α_i be manager i's share in his performance measure and let α_i be identical for both managers. Assume first that the managers are compensated via a profit sharing scheme, i.e. both managers receive a share of the actual firm profit. Then, a manager's expected compensation $E(\widetilde{c}_i)$ – given the value of p_i^0 for the current period – takes on the following form:

$$E(\widetilde{c}_i)=\alpha_i\cdot\int\limits_{p_j^0}\left[(p_i^0-1)\hat{x}_i-\frac{1}{2}b\hat{x}_i^2+(p_j^0-1)\hat{x}_j-\frac{1}{2}b\hat{x}_j^2\right]f(p_j^0)dp_j^0 \tag{4}$$

where $f(p_j^0)$ is the density function over p_j^0. Substituting (3) into (4) and differentiating yields the first order condition for the optimal reporting strategy:

$$\begin{aligned}\frac{\partial E(\widetilde{c}_i)}{\partial \hat{p}_i^0} &= p_i^0-\hat{p}_i^0+\int\limits_{p_j^0}\delta_j(p_j^0)f(p_j^0)dp_j^0=0 \\ \Leftrightarrow\quad \hat{p}_i^0-p_i^0 &= \int\limits_{p_j^0}\delta_j(p_j^0)f(p_j^0)dp_j^0=E\left[\delta_j(p_j^0)\right]\end{aligned} \tag{5}$$

where $\delta_j(p_j^0) = \hat{p}_j^0 - p_j^0$.[8] Thus, it is optimal for manager i to adjust his report by the expected deviation of manager j from his actual productivity parameter.[9] If we substitute (5) into manager j's first order condition we obtain for the optimal reporting strategy of both managers:

$$\hat{p}_i^0 - p_i^0 = \delta = \hat{p}_j^0 - p_j^0 \tag{6}$$

Thus, every reporting strategy that satisfies $\delta_i = \delta_j = \delta$ constitutes a Nash equilibrium. First, this is the case for truthful reporting behavior, i.e. $\delta = 0$, but not exclusively. Due to the ex ante information asymmetry both division managers know that $p_i^0 \in [p_{\min}^0, p_{\max}^0]$ whereas from headquarters' perspective $p_i^0 \in [p_{\min}^0 - \Delta, p_{\max}^0 + \Delta]$. Consequently, both manager can always over- or understate their productivity parameters by at least Δ, and reporting strategies where $0 < |\delta| \leq \Delta$ for all realizations of p_i^0 and p_j^0 also form pure strategy Nash equilibria. Moreover, these equilibria are all pareto efficient as manager i's biased report is just compensated by manager j's deviation and the same (efficient) resource allocation as in the truth telling case is obtained.

In contrast, reporting different $\delta_i(p_i^0)$ for different realizations of p_i^0 is not an equilibrium strategy as the best "response" of manager j is a constant deviation equal to $E\left[\delta_i(p_i^0)\right]$. But in this case it is again optimal for manager i to choose a deviation of the same magnitude for all p_i^0. Similarly, it can be shown that reporting strategies with $E\left[\delta_i(p_i^0)\right] > \Delta$ cannot be part of an equilibrium, either.[10]

From headquarters' perspective, the existence of multiple equilibria does not pose a problem as long as the resource allocation is always efficient, i.e. if always $\delta_i = \delta_j$. Yet, this is exactly the difficulty if none of the multiple equilibria emerges as a "focal" point to the players.[11] The equilibrium selection problem in this case is essentially unsolved by analytical theory. Moreover, as described above, pareto efficiency cannot serve as a selection criterium in this game. Consequently, inefficiencies in the profit sharing scheme may arise from inefficient resource allocation due to potential coordination failures, but not from the deviations from truth telling themselves.[12]

[8] δ_j depends on p_j^0 as it is generally possible to have different δ_j for different p_j^0.

[9] See also Loeb and Magat (1978) and Jennergren (1980) to this point.

[10] Also, there is no mixed strategy equilibrium in this model if we consider a mixed strategy of both managers over $2n+1$ equal steps between $\delta_i = -\Delta$ and $\delta_i = \Delta$. Therefore, and due to the fact that there has been expressed serious doubts about the implementation of mixed strategies in experiments, see e.g. Brown and Rosenthal (1990), we will concentrate on pure strategies in the following.

[11] See e.g. Schelling (1966), Ochs (1995), Camerer (2003), chap. 7.

[12] However, see Cohen and Loeb (1984) for potential problems of the profit sharing scheme when an

In contrast to the profit sharing scheme, truth telling always represents the dominant strategy equilibrium under the Groves mechanism. Under the specification of the Groves mechanism implemented in the experiment a manager's compensation is an increasing function of his own division's actual profit and the other division's reported profit. The reported profit is calculated based upon the reported productivity parameter and the resource units allocated due to this report. Thus, manager i's expected compensation is given by

$$E(\widetilde{c}_i) = \alpha_i \cdot [E(\widetilde{\pi}_i) + \hat{\pi}_j] = \alpha_i \cdot \int_{p_j^0} \left[(p_i^0 - 1)\hat{x}_i - \frac{1}{2}b\hat{x}_i^2 + (\hat{p}_j^0 - 1)\hat{x}_j - \frac{1}{2}b\hat{x}_j^2 \right] f(p_j^0)dp_j^0 \tag{7}$$

where $\hat{\pi}_j$ is the reported profit of division j calculated upon $\hat{p}_j^0$ and $\hat{x}_j$.[13] Substituting (3) into (7) and optimizing the managers' reports yields:

$$\hat{p}_i^0 = p_i^0 \tag{8a}$$

and

$$\hat{p}_j^0 = p_j^0 \tag{8b}$$

Thus, it is always optimal in the Groves mechanism to report truthfully, independent of the other manager's report. As this avoids inefficiencies due to coordination failures, the Groves mechanism is the theoretically superior budgeting instrument. Although managers can benefit by coordinating their reports and manipulating their reported productivity parameters upwards this does not form an equilibrium in a finitely repeated game under standard theoretical assumptions.[14]

We will now examine the effects of cheap talk on the theoretical results of our model. In general, unrestricted communication – as implemented in our experiment – can lead to a multitude of possible messages and thus to a multitude of new equilibria. Therefore, in the following we will particularly concentrate on communication strategies and messages which will be relevant for the experimental analysis.

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effort variable is introduced.

[13]Note that the general class of performance indicators derived in Groves (1976) and Groves and Loeb (1979) takes on the following form for manager i in this context: $\phi_i(p_j^0)\cdot(\widetilde{\pi}_i + \hat{\pi}_j) + \psi_i(p_j^0)$. $\phi_i(p_j^0)$ is a strictly positive function that depends only on division j's message, and $\psi_i(p_j^0)$ is an arbitrary function that depends only on division j's message. Thus, we set $\phi_i(p_j^0) = 1$ and $\psi_i(p_j^0) = 0$ in our experiment as in all other experimental studies of the Groves mechanism.

[14]See Loeb and Magat (1978). However, Kunz and Pfeiffer (1999) in an extension of Kreps, Milgrom, Roberts and Wilson (1982) show that the Groves mechanism can lead to rational cooperation if there is a positive probability for tit-for-tat players among the division managers.

Although the communication implemented in the experiment represents cheap talk in a game theoretical sense and thus is non-binding, it can play an important role for the coordination of players between different equilibria.[15] From a standard theoretical point of view cheap talk can matter if the players' announcements are self-committing and self-signalling: If a player's message is believed it creates incentives to fulfill it (self-committing) and a player has an incentive to send a message if and only if it is true (self-signalling) (Farrell and Rabin (1996)). This is indeed the case for the profit sharing scheme: If manager i communicates his δ_i during the communication phase he has an incentive to report this δ_i to headquarters as manager j has an incentive to choose his δ_j correspondingly.[16]

If communication is two-sided and unrestricted as it was in the experiment, the number of pareto efficient reporting strategies can increase even further compared to the case without communication. This is the case if players truthfully communicate their actual productivity parameters to their partners during the communication phase.[17] Then, additional pareto efficient equilibria emerge except for the case that we simultaneously have $p_i^0 = p_{\min}^0$ and $p_j^0 = p_{\max}^0$. This is due to the fact that the managers are now able to deviate from the truthful reports by more than Δ without changing the (efficient) resource allocation. For example, if both productivity parameters are identical every reporting strategy with $\hat{p}_i^0 = \hat{p}_j^0$ and $\hat{p}_i^0 \in [p_{\min}^0 - \Delta, p_{\max}^0 + \Delta]$ represents a Nash equilibrium.

Again it cannot be determined from a theoretical perspective which of the multiple equilibria will be chosen if none of the equilibria is "focal" for the players. Thus, in the communication case we might observe deviations from truth telling even more frequently than in the case without communication. However, as we have demonstrated above, the robustness of the profit sharing scheme is that all of these equilibria lead to efficient resource allocation. Therefore, despite a possibly lower frequency of truthful reports, communication is beneficial for headquarters under the profit sharing scheme due to improved coordination.

[15]See e.g. Farrell (1987, 1993) for a theoretical perspective, Cooper, DeJong, Forsythe, and Ross (1989, 1994) for experimental results.

[16]From a theoretical perspective, one-sided communication would be sufficient in this game to reach coordination between the two managers.

[17]Truthful communication of the actual productivities represents an equilibrium. Theoretically, there would also be an equilibrium if manager i communicated his actual productivity truthfully but manager j did not as long as manager j re-adjusts his report to headquarters. However, as this case is empirically not relevant it will not be considered in the following.

If, in contrast, managers are compensated according to the Groves mechanism communication is irrelevant from a standard theoretical perspective. The message of an overstatement of the productivity parameter during the communication is neither self-signalling nor self-committing and therefore does not affect managers' reports. Thus, profit sharing can at best be equivalent to the Groves mechanism from a theoretical perspective as both compensation schemes should lead to full efficiency under communication.

Yet, these standard theoretical predictions of the effects of communication on the Groves mechanism are in stark contrast to experimental findings. These findings show that decreasing social distance between experiment participants via communication increases cooperation between them even if communication is irrelevant from a theoretical point of view. Therefore, the effects of communication on both compensation schemes in reality are likely to differ more strongly than the standard theoretical predictions. With respect to the profit sharing scheme it should enable better coordination of the managers and decrease inefficient resource allocations due to coordination failures. In contrast, under the Groves mechanism communication could lead to increased cooperation despite its theoretical irrelevance and thus cause increased compensation costs for the firm. With respect to the real effects of communication it seems to be particularly beneficial for the profit sharing scheme that there is no collusion possibility for the division managers and the maximum compensation (not the optimum in terms of an equilibrium) is reached if headquarters reaches its maximum, too.

3 Experimental design and hypotheses

The experimental analysis consists of five different treatments: Groves mechanism with and without communication, Groves mechanism with communication and audits and profit sharing with and without communication.[18] All experimental sessions had two parts: the training and the payoff rounds. Before the 10 payoff rounds started the participants completed 12 training rounds to learn how their compensation scheme

[18]In fact, the experimental data presented here were gathered in two studies. In the first study, we implemented the Groves treatments with and without communication, in the second study we performed the Groves treatment with communication and audits as well as the profit sharing treatments with and without communication. However, as we had different participants in these two studies and did neither change the instructions nor the procedure (except for the adjustments necessary to account for the special characteristics of every treatment) there is no relevant difference between these two studies and thus we will not differentiate between them in the following.

worked. During these training rounds the participants had no real partner, but a computer simulated the decisions of the other player. The points earned during the training rounds had no effect on participants' income from the experiment. After having completed the training every participant was assigned a partner for all following 10 payoff rounds. The partner's identity was never revealed. This was all known to the participants.

In the experiment, we implemented a discrete version of the model analyzed in section 2. More precisely, the divisions' profit function $\pi_i(x_i)$ was given by:

$$\begin{aligned}
\pi_i(x_i) &= \begin{cases} p_i^0 \cdot x_i - x_i = (p_i^0 - 1) \cdot x_i & \text{for } \; x_i \leq 40 \\ 40 \cdot p_i^0 + (x_i - 40) \cdot (p_i^0 - 0.3) - x_i & \text{for } \; 40 < x_i \leq 100 \\ 40 \cdot p_i^0 + 60 \cdot (p_i^0 - 0.3) + (x_i - 100) - x_i & \text{for } \; 100 < x_i \end{cases} \\
\forall \;\; i &= 1,2
\end{aligned} \tag{9}$$

with $p_i^0 \in \{1.4, 1.5, ..., 2.1\}$. Thus, marginal revenue is again decreasing in x_i: For $x_i \leq 40$ it amounts to p_i^0, for $40 < x_i \leq 100$ to $p_i^0 - 0.3$, and for all $x_i > 100$ it is equal to 1. The general shape of the divisions' profit function according to (9) was common knowledge but the divisions' productivity parameters p_i^0 were uncertain. At the beginning of every round the values of p_i^0 for both divisions were randomly determined and every division manager was informed about his exact productivity parameter in the current round. We did not include a random variable $\widetilde{\varepsilon}_i$ into the profit function to avoid any distortions. However, the participants were informed that (except for the case of an audit in the corresponding Groves treatment) headquarters would never know their actual productivity parameter of a given round. Therefore, the only consequences of a misrepresentation of the productivity parameters were potential changes in the compensation.

Based upon the reported productivity parameters $\hat{p}_i^0$ and $\hat{p}_j^0$ headquarters allocated $\bar{x} = 120$ resource units among the two divisions. For $\hat{p}_i^0 \leq \hat{p}_j^0$ the allocation was as follows:

$$\begin{array}{ll}
x_i = 20 \text{ and } x_j = 100 & \forall \;\; \hat{p}_i^0 < \hat{p}_j^0 - 0.3 \\
x_i = 40 \text{ and } x_j = 80 & \forall \;\; \hat{p}_j^0 - 0.3 \leq \hat{p}_i^0 < \hat{p}_j^0 \\
x_i = x_j = 60 & \forall \;\; \hat{p}_i{}^0 = \hat{p}_j{}^0
\end{array} \tag{10}$$

The reverse holds for $\hat{p}_i^0 \geq \hat{p}_j^0$. This allocation scheme is optimal if p_i^0 and p_j^0 are reported truthfully.[19]

In order to account for the problem of multiple Nash equilibria in a profit sharing scheme we introduced an ex ante information asymmetry of $\Delta = 0.1$ in these treat-

[19] Note that if $p_i{}^0 = p_j{}^0$ an allocation of 80/40 yields the same firm profit.

ments. Thus, for the participants' potential reports we had $\hat{p}_i^0 \in \{1.4, 1.5, ..., 2.1\}$ in the Groves treatments and $\hat{p}_i^0 \in \{1.3, 1.4, ..., 2.2\}$ in the profit sharing treatments.

The compensation in the profit sharing treatments was given by

$$P_i = 0.1 \cdot [\pi_i(\widehat{x}_i) + \pi_j(\widehat{x}_j)] \tag{11}$$

where P_i represents the points collected in every round. Points were converted into Euros after the experiment and 7 points corresponded to 1 Euro. According to (11), compensation in these treatments simply equaled 10% of the actual firm profit. From this and the information asymmetry of $\Delta = 0.1$ it directly follows that there are always three pareto efficient pure strategy Nash equilibria: $\delta_i = \delta_j = 0$, $\delta_i = \delta_j = 0.1$ and $\delta_i = \delta_j = -0.1$. The example in Table 1 with $p_i^0 = 1.8$ and $p_j^0 = 1.7$ further shows that additional equilibria emerge in the communication treatment if both players truthfully communicate their actual productivities during the communication phase. In this case, not only reporting strategies with $\delta_i = \delta_j$ and $|\delta_i| = |\delta_j| \leq 0.1$ form equilibria for the two players but all pairs of reported productivities which do not affect optimal resource allocation. For example, in Table 1 this is the case for $\hat{p}_i^0 = 2.2$ and $\hat{p}_j^0 = 2.1$, i.e. $\delta_i = \delta_j = 0.4$, and $\hat{p}_i^0 = 1.4$ and $\hat{p}_j^0 = 1.3$, i.e. $\delta_i = \delta_j = -0.4$. Moreover, due to the discrete model structure of the experiment every pair of reported productivity parameters where $\delta_i \neq \delta_j$ but the optimal resource allocation is left unchanged also represents an equilibrium. E.g. this is the case for $\hat{p}_i^0 = 2.0$ and $\hat{p}_j^0 = 1.7$.[20]

In the Groves treatments with and without communication the managers' compensation in every round was given by:

$$P_i = 0.1 \cdot [\pi_i(\widehat{x}_i) + \widehat{\pi}_j(\widehat{x}_j)] \tag{12}$$

Thus, in every round the manager earned 10% of his division's actual profit $\pi_i(\widehat{x}_i)$ and the other division's reported profit $\widehat{\pi}_j(\widehat{x}_j)$. In contrast, in the Groves treatment with communication and audits the managers' compensation amounted to:

$$P_i = \begin{cases} 0 & \text{with audit and } \hat{p}_i^0 \neq p_i^0 \\ 0.1 \cdot [\pi_i(\widehat{x}_i) + \widehat{\pi}_j(\widehat{x}_j)] & \text{else} \end{cases} \tag{13}$$

Thus, whenever a participant was audited and his reported productivity parameter did not correspond to his actual parameter of the current round he lost all points of this round. This was to reflect the consequences of a negative internal audit in reality. For the participant's partner there were no consequences from the audit unless he

[20] We will come back to these cases in the analysis of the experimental results.

was audited himself and a deviation from truth telling was detected. In every round 2 of the 20 participants of a session were audited. The audit was independent of previous audits, the reported productivity parameter and the partner's audit. Thus, in every round there was a 10%-probability of being audited. This was all known to the participants.

As shown in section 2, truthful reporting is the dominant strategy in the Groves mechanism. Table 2 illustrates this for the case $p_i^0 = 1.8$ and displays the compensation of manager i for different $(\hat{p}_i^0, \hat{p}_j^0)$-pairs. It can be seen that the vector of truthful reports dominates all other vectors. If we also assume $p_j^0 = 1.8$, the table further illustrates the players' prisoners' dilemma. If they could make binding agreements and agree to report $\hat{p}_i^0 = \hat{p}_j^0 = 2.1$ they could realize a compensation of 10.2 points compared to 8.4 points for truth telling. However, given the partner's overstatement every manager has an incentive to report truthfully which would further increase the compensation to 10.8 points. At a first glance the combination of $\hat{p}_i^0 = 1.8$ and $\hat{p}_j^0 = 2.1$ seems to represent a (pareto superior) Nash equilibrium compared to truth telling as manager j realizes a compensation of 8.4 independent of whether he reports $\hat{p}_j^0 = 2.1$ or $\hat{p}_j^0 = 1.8$ but manager i realizes an increased compensation. However, due to the uncertainty about the other player's actual productivity parameter manager j can only expect $\hat{p}_i^0 = p_i^0$ but not $\hat{p}_i^0 = 1.8$. Consequently, truthful reporting behavior is the dominant strategy equilibrium in the Groves mechanism.

Though, as we mentioned above, the Groves treatment with communication and audits was performed after we had obtained the results from the two other Groves treatments and was motivated by these results. From an experimental point of view the positive auditing probability particularly served the purpose to exclude some explanations for potential collusion strategies of the participants. First, as was just described, players may be indifferent between truth telling and overstatements of their productivities in the treatments without audits for some *given* (p_i^0, p_j^0)-pairs. Due to the positive auditing probability this is no longer the case. For every parameter constellation and every given report of the partner, truth telling *strictly* dominates any other reporting behavior (in terms of a larger $E(P_i)\ \forall\ p_j^0, \hat{p}_j^0$). That means that in the treatment with audits there is an even stronger incentive for the participants to deviate from agreements with their partner. Second, the positive auditing probability unambiguously draws the participants' attention to truth telling as a desirable reporting strategy (from an individual and from headquarters' perspective). Thus, deviations from truth telling due to incomplete understanding are less likely in this treatment.

However, even with audits, it would have been beneficial for risk neutral participants to make binding agreements about overstatements of the productivity parameter if this had been possible. For example, reporting always $\hat{p}_i^0 = \hat{p}_j^0 = 2.1$ yields an ex ante expected compensation (in points) of 9.9 per round in the treatment without audits and of 9.06 in the treatment with audits compared to an ex ante expected value of 8.45 for truth telling. However, as in reality, it was not possible for the participants to conclude binding agreements in the experiment. Furthermore, we excluded the possibility of side payments between the players.[21]

From the preceding analysis we can derive the following hypotheses[22]:

Groves mechanism

Hypothesis 1a: The Groves mechanism induces truthful reporting behavior.

However, as Kunz and Pfeiffer (1999) have shown, if there is a positive probability of tit-for-tat players among the participants rational cooperation can emerge in the Groves mechanism, similar to the cooperation usually observed in public good experiments.[23] Yet, this cooperation declines during the game. Thus, we can state the alternative hypothesis:

Hypothesis 1b: Deviations from truth telling in the Groves mechanism will decrease in the course of the experiment and will tend to 0.

Similarly, as Hypothesis 1a is very strong and deviations are likely to occur we also formulate two weaker hypotheses describing the effects of the audits on experimental outcome if there are deviations from truth telling in the treatments without audits.

Hypothesis 2: Adding a positive auditing probability to the Groves treatment with communication (i) reduces average misrepresentation and (ii) increases the frequency of truthful reports.

[21]Note that analytical studies analyzing coalitions in the Groves mechanism explicitly rely on the assumption of enforceability of the reporting strategies and side payments agreed upon in the coalition, see Green and Laffont (1979) and Crémer (1996). However, as the experimental results will show, binding contracts and side payments are not necessary to induce collusion under this incentive scheme.

[22]Due to their importance for the evaluation of the two incentive schemes the hypotheses on headquarters' net earnings will be formulated separately. They will all be analyzed in section 4.3.

[23]See e.g. Ledyard (1995) for an overview of these experiments.

Hypothesis 3: Adding a positive auditing probability to the Groves treatment with communication increases headquarters' net earnings.

Profit Sharing

Unless one of the multiple equilibria of the profit sharing scheme is "focal" for the participants we can state the following hypotheses:

Hypothesis 4: The possibility of preplay communication in the profit sharing scheme (i) increases the number of coordinated reports to headquarters but (ii) decreases the frequency of truthful reports.

Hypothesis 5: The possibility of preplay communication in the profit sharing scheme increases headquarters' net earnings.

Groves mechanism vs profit sharing

Hypothesis 6: Truthful reports occur more frequently in the Groves mechanism than in (i) the profit sharing treatment without communication and (ii) the profit sharing treatment with communication.

Hypothesis 7: Headquarters' net earnings in the Groves mechanism are (i) larger than under the profit sharing scheme without communication and (ii) as large as under the profit sharing scheme with communication.

The participants of the experiment took over the role of the division managers, whereas the role of headquarters was played by a computer. The instructions informed the participants about the profit functions of their divisions according to (9), the resource allocation according to (10) and their compensation according to (11), (12) or (13).[24] At the end of the instructions and before the training started, the participants received a summary of all functions. In the communication treatments, the participants further received communication rules. The instructions appeared on computer screens and

[24] However, the players were never told that the resource allocation scheme according to (10) represents the optimal allocation given truthful reporting.

were simultaneously read aloud.[25]

In the communication treatments the participants were given the possibility to communicate with their partner after they had learned their actual productivity parameters for the current round but before they had to report their parameters. Communication was possible via a chat program and partners remained completely anonymous to each other during the whole experiment.[26] Thus, both with respect to communication possibilities in corporate reality and with respect to forms of communication implemented in other experimental studies – often face-to-face interaction – this represents one of the weakest forms of communication.[27] The communication time was 3.5 minutes in the first round and was reduced to 1.5 min in the course of the experiment.

At the beginning of every round the participants were informed about their division's actual productivity parameter for the current round. At the end of every round they were informed about the resource allocation, the reported productivity of their partner and their compensation for this round. In the profit sharing treatments they were also informed about the actual productivity parameter of their partner in the current period as they could have easily calculated it themselves from their compensation. In all Groves treatments the actual productivity remained private information of every player during the whole experiment. To facilitate comparisons between different rounds the participants were also shown the data of all previous rounds.

The experiment was run at the ExECUTe laboratory of the Institute of Management and Economics of the Clausthal University of Technology (CUT). In total, 198 students and employees of the CUT participated in the experiment, 38 in the Groves treatment without communication and 40 in every other treatment. The sessions lasted between 80 and 150 minutes. All participants received a show-up fee of 10 EUR, the additional variable remuneration was 12.30 EUR on average, with a minimum of 8.20 EUR and a maximum of 15.14 EUR.[28]

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[25] Note that we used "neutral" vocabulary in the instructions. The instructions are available from the authors upon request.

[26] The players were explicitly forbidden to reveal their identity or to make arrangements beyond the game in the laboratory. If so, they would have lost their entire variable compensation from the experiment. In the analysis of the communication no evidence could be found for rule breaking, not even for any attempt.

[27] In general, the more direct the contact between the players during the communication the better is the cooperation. See Frohlich and Oppenheimer (1998), Brosig, Weimann and Ockenfels (2003), Paese, Schreiber and Taylor (2003) to this point. However, Bochet, Page and Putterman (2003) find that communication in a chat room is nearly as efficient in inducing cooperation in their experiment as face-to-face interaction.

[28] The experiment was realized with the software "Toolkit for Economic Experiments with Commu-

4 Experimental results

4.1 Groves mechanism

Following Waller and Bishop (1990) we use the following measures of misrepresentation for the subsequent analysis[29]:

$$\Delta_{abs} = \widehat{p}_i^0 - p_i^0 \tag{14}$$

$$\Delta_{rel} = \begin{cases} \frac{\widehat{p}_i^0 - p_i^0}{p_i^0 - 1.4} & \text{for } \widehat{p}_i^0 < p_i^0 \\ 0 & \text{for } \widehat{p}_i^0 = p_i^0 \\ \frac{\widehat{p}_i^0 - p_i^0}{2.1 - p_i^0} & \text{for } \widehat{p}_i^0 > p_i^0 \end{cases} \tag{15}$$

Table 3 shows the descriptive statistics of the experimental data for the three Groves treatments as well as the results of the Mann-Whitney U-tests we conducted.[30] Figure 1 displays the average absolute misrepresentation of the three treatments for all rounds.

We will first analyze the treatments without audits and come back to the auditing treatment later. Table 3 shows that neither in the treatment with nor in the treatment without communication the Groves mechanism induced truthful reporting behavior. In the treatment without communication only 44.47% of the reports were truthful, whereas in the communication treatment the frequency of truth telling even declined to 21.5%. The results of the noncommunication treatment are very close to those of Waller and Bishop (1990) who find 48% truthful reports, 33% overstatements and 19% understatements in their Groves treatment.

The table further reveals that mean absolute and relative misrepresentations are positive in both treatments and more than three times larger in the treatment with communication than in the treatment without. Mann-Whitney U-tests show that the absolute and relative misrepresentation in both treatments are significantly different from 0 ($p \leq 0.001^{***}$ in all cases). Thus, in contrast to the standard theoretical prediction of Hypothesis 1a the Groves mechanism without audits does not lead to truthful reporting behavior.

As the communication implemented in the experiment is cheap talk in the game-theoretical sense both treatments should not differ from a theoretical point of view.

nication" (TEEC).

[29]The relative misrepresentations for the profit sharing treatments are adjusted to account for the larger misrepresentation potential.

[30]For the Mann-Whitney U-tests we used individual averages across rounds as unit of observation in order to avoid problems of statistical dependence. E.g. for the absolute misrepresentation we used $\overline{\Delta}^i_{abs} = \sum_{t=1}^{10} \Delta^{i,t}_{abs}/10$. Thus, for every comparison between treatments we had 38 or 40 observations per treatment, one for each subject. All tests conducted are two-sided.

However, the results of Table 3 reveal that misrepresentation in the treatment with communication is significantly larger than in the treatment without. Furthermore, the frequency of truth telling is much smaller in the communication treatment and this difference is highly significant (χ^2, $p < 0.001^{***}$). Figure 1 shows that the deviations from truth telling in the communication treatment are indeed larger than in the noncommunication treatment in all rounds. The figure also reveals that contrary to the prediction of Hypothesis 1b a negative time trend does not exist. Linear regressions support this finding as they exhibit an insignificant time coefficient for both misrepresentation measures in the noncommunication treatment and even a significantly *positive* coefficient in the communication treatment.

These deviations from truth telling will now be analyzed in more detail. As mentioned above, prior experimental studies find significant deviations from truth telling in the Groves mechanism but only weak evidence for collusive behavior of the participants. Similar to Waller and Bishop (1990), Chow, Hirst and Shields (1994) and Chow, Hwang and Liao (2000), the evidence for collusive behavior in our noncommunication treatment is not very strong. Pairwise analysis of the reported productivity parameters reveals that simultaneous overstatements occurred in only 33 of the 190 cases. Moreover, only the behavior of one pair can be unambiguously attributed to collusive behavior at the expense of headquarters. The simultaneous overstatements of the other pairs seem to be the outcome of individual strategies and do not occur systematically.[31] Thus, the overstatement observed on average in this treatment is rather due to incomplete understanding of the Groves mechanism or social preferences of the participants (like e.g. altruism) than to attempts to build a reputation as cooperative player. The fact that incomplete understanding might have been relevant for the observed behavior receives further support from the analysis of the questionnaires answered by the participants after the experiment. The first question referred to the optimal strategy *given* the partner's report and should control for the participants' understanding of the Groves mechanism. In the treatment without communication only 63% answered the question correctly by indicating truthful reporting behavior, in the communication treatment this fraction even declined to 50%. We will come back to this below.[32]

[31]It is often observed that players overstate high productivities and report low productivities truthfully or overstate productivities independent of their partner's report.

[32]Likewise, Waller and Bishop (1990) attribute part of their results to difficulties in understanding the comparatively complex Groves mechanism. Güth, Schmidtberger and Schwarze (1983) also

However, our conclusion about the causes of the observable deviations from truth telling is completely reversed in the communication treatment. Table 4 displays the analysis of the participants' communication in this treatment. All but one pair used the possibility to communicate.[33] Panel 1 of the table reveals that during the communication the overwhelming majority of the participants informed their partner truthfully about their actual productivity parameter.[34] Panel 2 of Table 4 displays the behavior of the participants after they had agreed upon a reporting strategy that deviated from truth telling. It shows that over 95% of the agreements were met and that even in the last rounds the number of broken agreements did not increase.

As truth telling is the dominant strategy anyway, we did not include agreements to truthful reporting into the table. However, this also excludes cases where participants that were continuously cooperating could not overstate their productivity parameter as it was equal to 2.1. The number of these cases is particularly large (6 and 5) in rounds 8 and 10 and thus explains the relatively low number of agreements in these rounds. Table 4 therefore confirms the observation from Figure 1 that there is no endgame effect in this experiment. In the overwhelming number of cases the cooperation between the participants does not break down in the last rounds and we observe *stable* collusion strategies in the Groves treatment with communication.

So far however, the question remains whether the increase in cooperation in the communication treatment can be attributed to a fundamental change in the participants' reporting behavior or whether it is only due to the fact that in this treatment more participants were convinced that overstatement would be individually optimal for them. As we mentioned above, the latter possibility receives some support from the fact that the number of players that correctly answered the question about their individually optimal strategy (given the partner's report) is smaller in the treatment with communication than in the treatment without. Therefore, Table 5 analyzes the misrepresentation measures contingent on the participants' answer to this question.

The first column shows that in the treatment without communication both misrepresentation measures are larger when overstatements are considered to be individ-

find incomplete understanding of the Vickrey auction which works in a similar way as the Groves mechanism.

[33]However, three pairs could not agree during the whole game on the player that should reveal his information first.

[34]Similarly, Schwartz and Young (2002) analyze cheap talk in a budgeting context and find that for repeated interactions between two participants the productivities were truthfully communicated to the partners in over 80% of the cases even if they could not be verified ex post.

ually optimal than for truthful reporting behavior. They even become negative for participants that believed understatement was optimal for them. The differences are significant (Mann-Whitney U, $p < 0.05^{**}$ in all but one case and $p = 0.068^{*}$ in this case). Thus, in the treatment without communication participants' reporting behavior differed significantly contingent on what they considered to be individually optimal. The second column of Table 5 shows that although average misrepresentation in the communication treatment is still largest for overstatement as the individually optimal strategy and lowest for understatement, the differences are a lot smaller. Moreover, Mann-Whitney U-tests reveal that neither difference is significant at conventional levels ($p > 0.4$ in all cases). We interpret this as evidence for fundamental differences between the participants' reporting behavior in the treatments with and without preplay communication. While in the treatment without communication participants' reports differed according to what they considered as individually optimal, the participants in the communication treatment chose reporting strategies that were beneficial for both partners, irrespective of their considerations about the individually optimal strategy.

These results are quite surprising, particularly with respect to the stability of the participants' collusion strategies. Thus, we implemented the Groves treatment with communication and audits in order to further analyze this collusion. As we have described above, this treatment should strongly decrease the probability that the results of the communication treatment are mainly driven by incomplete understanding of the Groves mechanism or weak incentives to deviate from agreements with the partner.

Figure 1 shows that average absolute misrepresentation in the treatment with communication and audits remains positive in every round. Although average misrepresentation in this treatment declines to a level slightly above the level in the noncommunication treatment, deviations from truth telling remain significant in this treatment, too (Mann-Whitney U, $p < 0.001^{***}$). Thus, Hypothesis 1a definitely has to be rejected. Moreover, there is still no negative time trend in the misrepresentation and this is confirmed by the regressions we ran. Consequently, we also have to reject Hypothesis 1b. However, Table 3 confirms the predictions of Hypothesis 2: First, the introduction of the positive auditing probability significantly reduces both Δ_{abs} and Δ_{rel}. Second, the frequency of truth telling is significantly larger in the treatment with communication and audits than in the two other Groves treatments (χ^2, $p < 0.001^{***}$ in both cases).

Although Table 3 shows that the absolute misrepresentation measures in the treatment without communication and the treatment with communication and audits differ only marginally and that the relative misrepresentation measures are insignificantly different, misrepresentations in these two treatments differ strongly with respect to their structure. While deviations from truth telling in the noncommunication treatment can be traced back to incomplete understanding and social preferences, the auditing treatment leads to either coordinated truth telling or coordinated misrepresentations. This is confirmed by Panel 3 of Table 4. Again, we only display agreements upon reporting strategies that deviated from truth telling. The number of these agreements varies strongly in the course of the experiment. However, again more than 94% of the agreements are met. The number of agreements does not decrease very strongly in the last rounds and the overwhelming majority of the players sticks to their agreements.[35] Moreover, only three pairs agreed to report their parameters truthfully in (nearly) all rounds. The agreements of all other pairs varied between truth telling and misrepresentations. This confirms the finding from Figure 1 that there is no end-game effect in this treatment, either. Furthermore, it shows that the findings from the communication treatment without audits are quite robust. Although the positive auditing probability decreases the frequency of deviations from truth telling and therefore average misrepresentation, we still observe stable collusion strategies of the participants. Thus, the results of all Groves treatments differ significantly from the theoretical predictions.

4.2 Profit sharing

Table 6 displays the descriptive statistics for the profit sharing treatments and the results of the Mann-Whitney U-tests we conducted. The table shows that both misrepresentation measures in the two treatments do not differ significantly. Figure 2 displays how Δ_{abs} evolved in the profit sharing treatments during the experiment. It can be seen that Δ_{abs} is always positive in the treatment without communication and positive in all but one round in the treatment with communication and that it remains quite stable in both treatments during the experiment.

Mann-Whitney U-tests reveal that the deviations from truth telling are significant both in the noncommunication treatment ($p < 0.05^{**}$ for both misrepresentation measures) and in the communication treatment ($p < 0.01^{***}$ for the absolute misrepresentation measure). Yet, as we explained in section 2, the efficiency of a profit sharing

[35] Note that the pair causing both deviations in round 9 reaches an agreement on nontruthful reporting behavior in round 10 and both players stick to the agreement.

scheme does not depend on the frequency of truthful reports but on the participants' coordination on an equilibrium that yields optimal resource allocation. Therefore, Table 7 shows the average number of equilibrium "hits" (i.e. the play of equilibrium strategies ex post) per round in both treatment.

Panel 1 of Table 7 reveals that coordination occurred in only 30% of the cases in the noncommunication treatment. It further shows that the truth telling equilibrium is hit more often than the two other equilibria $\delta_i = \delta_j = 0.1$ and $\delta_i = \delta_j = -0.1$.[36] Truthful reporting behavior thus seems to represent a focal point for the participants. However, it is not strong enough to coordinate all reports.

It is surprising that the average number of equilibrium hits in rounds 6-10 was as large as in rounds 1-5. Obviously, repeated interaction does not improve coordination in the profit sharing treatment without communication. At a first glance, this seems to indicate that the results are essentially driven by incomplete understanding. However, this is contradicted by two other findings: First, *in addition* to the coordinated reports there were on average 18.8 reported productivity parameters (i.e. 47% of all reports) in every round with $|\delta_i| \leq 0.1$. Thus, these reports could have led to an equilibrium but did not due to the partner's differing report. Second, the two questions of the questionnaire that should control for participants' understanding were correctly answered by 77.5% and 80% of the participants.[37] Together, these findings support the explanation that the results are mainly caused by coordination problems rather than by incomplete understanding. The losses in efficiency due to these coordination failures will be analyzed in section 4.3.

Panel 2 of Table 7 shows that consistent with the predictions of part (i) of Hypothesis 4 the possibility of preplay communication strongly increased coordination. The fraction of reports with $\delta_i = \delta_j$ more than doubled to 63%. The analysis of the communication shows that participants informed their partner about their actual productivity parameters in 91% of the cases and that this information was truthful in over 98% of the cases. However, equilibria with $\delta_i = \delta_j \neq 0$ were chosen less frequently (with respect to all cases with $\delta_i = \delta_j$) than in the noncommunication treatment. Only in the last round one of these equilibria with $\delta_i = \delta_j = 0.6$ explains part of the ob-

[36]There were also 3 cases in the noncommunication treatment where $\delta_i = \delta_j > 0.1$ or $\delta_i = \delta_j < -0.1$. However, we did not include them into Table 7 as deviations from truth telling with absolute values larger than 0.1 do not lead to an equilibrium with certainty (i.e. for all p_i^0) in the noncommunication treatment. In the communication treatment however, the corresponding cases are included into Table 7 if participants agreed upon these reports during the communication, see section 3.

[37]Note that 15% of the participants answered both questions incorrectly.

servable magnitude of Δ_{abs} in Figure 2. Thus, truth telling obviously serves as a focal point during the communication. This already contradicts part (ii) of Hypothesis 4 which predicts a decrease in the frequency of truth telling. Moreover, if we consider all reported productivities we also find that the overall frequency of truthful reports is significantly larger in the treatment with communication than in the treatment without (χ^2, $p < 0.001^{***}$). Thus, part (ii) of Hypothesis 4 has to be rejected.

Yet, it was shown in section 3 that due to the discrete model structure $\delta_i = \delta_j$ is not a necessary condition for an equilibrium in the communication treatment as long as the reported productivity parameters induce efficient resource allocation. Pairs of reported productivities with $\delta_i \neq \delta_j$ but efficient resource allocation occurred on average 2.4 times per round (12%). Moreover, when analyzing the communication we found strong evidence that participants were indeed aware of the fact that only resource allocation influenced their compensation but not the exact magnitude of the deviations from truth telling.[38] Thus, in 75% of the cases in the communication treatment the reporting strategies represented pareto efficient equilibrium play which is significantly larger than the corresponding 30% in the noncommunication treatment (χ^2, $p < 0.001^{***}$). This is consistent with the predictions of part (i) of Hypothesis 4.[39]

The following section will compare the implications of the results obtained so far for the comparison between the Groves mechanism and the profit sharing scheme.

4.3 Profit sharing vs Groves

First, we will compare the deviations from truth telling. As the maximum over- and understatement in the profit sharing treatment were always 0.1 larger than in the Groves treatments we will only present the comparison of the relative misrepresentation measures.[40] Table 8 shows that Δ_{rel} is significantly larger in all Groves treatments than in both profit sharing treatments. This already points at a potential disadvantage of the Groves mechanism from headquarters' perspective. However, the relevant measure for the comparison between the two incentive schemes is not deviation from truth

[38] For example, after two participants had truthfully exchanged their actual productivity parameters of $p_i^0 = 1.6$ and $p_j^0 = 1.7$ and player j had proposed to report $\hat{p}_i^0 = 1.6$ and $\hat{p}_j^0 = 1.9$, player i noted (translated from German): "As long as you report a larger productivity you get more resource units. Thus, we can report 1.6:1.7 or 1.6:1.9, that makes no difference."

[39] Note that if we only consider the cases where $\delta_i = \delta_j$ we obtain the same level of significance.

[40] If we use Δ_{abs} instead of Δ_{rel} the differences in Table 8 remain significant except for the comparisons with the Groves treatment without communication.

telling but headquarters' net earnings.

To measure the quality of the incentive schemes we calculate their efficiency losses by subtracting headquarters' actual earnings (net of compensation costs) from headquarters' net earnings in case of truth telling.[41] The efficiency loss in the Groves treatment with communication and audits considers that participants did not receive any compensation in case they were audited and a deviation from truth telling was revealed but does not include any costs for these audits. Table 9 displays the mean and median efficiency losses per round and pair for the different treatments as well as the corresponding Mann-Whitney U-tests.[42]

The table shows that the efficiency loss is lowest in the profit sharing treatment with communication and largest in the Groves treatment with communication. Consistent with Hypothesis 3 the introduction of audits significantly decreases the efficiency loss of the Groves treatment with communication. However, the efficiency loss in the treatment with audits is only insignificantly smaller than in the Groves treatment without communication. Moreover, recall that the former efficiency loss does not include any auditing costs.

When the Groves mechanism is compared to the profit sharing scheme both parts of Hypothesis 7 have to be rejected: (i) None of the Groves treatments has a significantly lower efficiency loss than the profit sharing treatment without communication and (ii) the efficiency loss in the profit sharing treatment with communication is significantly lower than in all Groves treatments. Moreover, while the efficiency losses in both Groves treatments with communication are larger in the last five rounds than in the first five rounds, the reverse holds in the profit sharing treatments. This indicates improved coordination in the profit sharing case and further confirms participants' stable collusion strategies in the two Groves treatments.

Finally, a comparison of the two profit sharing treatments shows that communication not only improves participants' coordination but also increases headquarters' net earnings (Hypothesis 5).

Therefore, from headquarters' perspective – and in contrast to the theoretical pre-

[41] We did not directly compare headquarters' actual earnings in the different treatments as due to the randomization of the productivity parameters headquarters' net earnings for truth telling were somewhat larger in the profit sharing treatments than in the Groves treatments. Thus, using actual net earnings would favor profit sharing even if the efficiency losses under Groves and profit sharing were equal.

[42] Note that the number of observations is now reduced to 19 and 20 per treatment, one for each pair.

dictions – profit sharing is superior compared to the Groves mechanism in our experimental study. With respect to truth telling, statistical analyses show that the frequency of truth telling is significantly larger in the Groves treatment with audits than in the profit sharing treatment without communication but significantly lower than in the profit sharing treatment with communication. This is consistent with the prediction of part (i) of Hypothesis 6 but contradicts part (ii). Thus, even if truth telling has some value for headquarters beyond optimal resource allocation, the Groves mechanism would not be preferred to the profit sharing scheme in our model structure.

5 Conclusion

This paper experimentally explores the efficiency of the Groves mechanism and a profit sharing scheme in a corporate budgeting context. Furthermore, it examines the effects of anonymous communication on both incentive schemes. This establishes a stronger link to corporate reality with its various communication possibilities.

Our results show that although truth telling is the dominant strategy equilibrium in the Groves mechanism we do not find truthful reporting behavior of the participants in our experiment. In the Groves treatment without communication these deviations can be attributed to incomplete understanding and social preferences but there is only weak evidence for collusive behavior. This changes fundamentally in the communication treatment. Although preplay communication is anonymous and represents cheap talk, it leads to *stable* collusion strategies of the participants and overstatements of the productivity parameters. The introduction of a positive auditing probability decreases average misrepresentation and increases the frequency of truth telling. However, it cannot break up the participants' stable collusion strategies and leads to either coordinated truth telling or coordinated misrepresentation of productivities.

In the profit sharing treatments, truth telling is a Nash equilibrium for the participants. However, this equilibrium is not unique. According to this, we observe coordination failures and inefficient resource allocation in the treatment without communication. As predicted from the theoretical analysis, the communication possibility strongly increases equilibrium play by the participants.

To compare the efficiency of the two incentive mechanisms we examined headquarters' earnings (net of compensation costs) and found that they are larger in the profit sharing treatments than in all Groves treatments. Thus, although the Groves mechanism is superior from a theoretical perspective, the profit sharing scheme turns out to be advantageous in our experimental setting. This is essentially due to the effects of the communication possibility on both incentive schemes. In the profit sharing treatments cheap talk is theoretically relevant and – consistent with the theoretical predictions – improves coordination in the experiment. This is beneficial for both the division managers and headquarters as it helps to avoid inefficient resource allocation due to coordination failures. Accordingly, headquarters' net earnings in the profit sharing treatment with communication are significantly larger than in all other treatments. In contrast, cheap talk does not matter from a theoretical perspective in the Groves treatments but, as the experiment has shown, is relevant when implemented in the experiment as it improves cooperation between division managers. Yet, this cooperation is detrimental for headquarters as it leads to overstated productivities and thus increases compensation costs. In the experiment, headquarters' net earnings in the Groves treatment with communication are significantly smaller than in any other treatment.

We argue that with respect to corporate reality with its various communication possibilities our results contribute to explain why the Groves mechanism is not observed as an incentive scheme in budgeting processes in reality. While this incentive scheme is collusion proof from a theoretical perspective, our experimental analysis has shown that it is not when implemented in practice.

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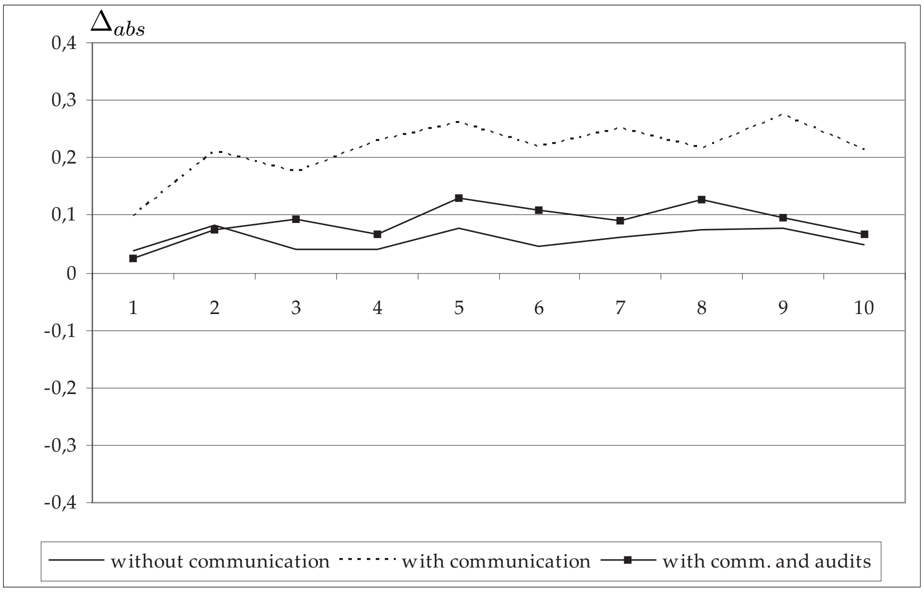

Figure 1: Mean absolute misrepresentation in the Groves treatments.

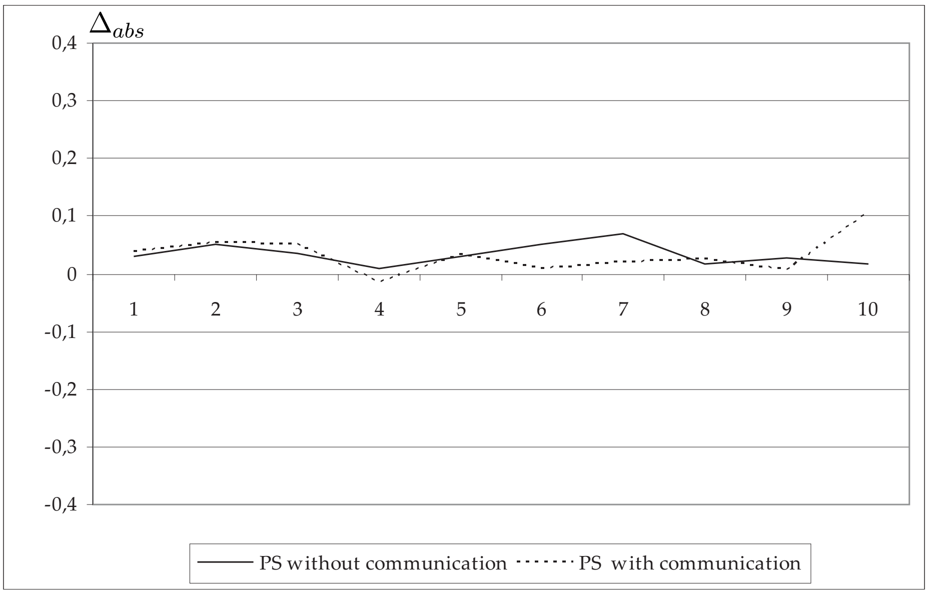

Figure 2: Mean absolute misrepresentation in the profit sharing treatments.

	$\widehat{p}_j^0$	1.3	1.4	1.5	1.6	1.7	1.8	1.9	2.0	2.1	2.2
	1.3	7.8	7.6	7.6	7.6	6.8	6.8	6.8	6.8	6.8	6.8
	1.4	8.0	7.8	7.6	7.6	7.6	6.8	6.8	6.8	6.8	6.8
	1.5	8.0	8.0	7.8	7.6	7.6	7.6	6.8	6.8	6.8	6.8
	1.6	8.0	8.0	8.0	7.8	7.6	7.6	7.6	6.8	6.8	6.8
$\widehat{p}_i^0$	1.7	7.6	8.0	8.0	8.0	7.8	7.6	7.6	7.6	6.8	6.8
	1.8	7.6	7.6	8.0	8.0	8.0	7.8	7.6	7.6	7.6	6.8
	1.9	7.6	7.6	7.6	8.0	8.0	8.0	7.8	7.6	7.6	7.6
	2.0	7.6	7.6	7.6	7.6	8.0	8.0	8.0	7.8	7.6	7.6
	2.1	7.6	7.6	7.6	7.6	7.6	8.0	8.0	8.0	7.8	7.6
	2.2	7.6	7.6	7.6	7.6	7.6	7.6	8.0	8.0	8.0	7.8

Table 1: Compensation of managers i and j under profit sharing for different pairs of reported productivities if $p_i^0 = 1.8$ and $p_j^0 = 1.7$.

	$\widehat{p}_j^0$	1.4	1.5	1.6	1.7	1.8	1.9	2.0	2.1
	1.4	6.0	6.0	6.8	7.6	7.8	8.8	9.8	10.8
	1.5	6.8	6.6	6.8	7.6	8.4	8.8	9.8	10.8
	1.6	6.8	7.2	7.2	7.6	8.4	9.2	9.8	10.8
$\widehat{p}_i^0$	1.7	6.8	7.2	7.6	7.8	8.4	9.2	10.0	10.8
	1.8	7.0	7.2	7.6	8.0	8.4	9.2	10.0	10.8
	1.9	7.0	7.2	7.6	8.0	8.4	9.0	10.0	10.8
	2.0	7.0	7.2	7.4	8.0	8.4	8.8	9.6	10.8
	2.1	7.0	7.2	7.4	7.6	8.4	8.8	9.2	10.2

Table 2: Compensation of manager i under the Groves mechanism for different pairs of reported productivities if $p_i^0 = 1.8$.

Panel 1: Number of reports

	without communication	with communication	with comm. and audits
Understatements	72	23	21
	(18.95%)	(5.75%)	(5.25%)
Truthful reports	169	86	257
	(44.47%)	(21.50%)	(64.25%)
Overstatements	139	291	122
	(36.58%)	(72.75%)	(30.50%)
Total	380	400	400
	(100%)	(100%)	(100%)

Panel 2: Mean absolute misrepresentation (Δ_{abs})

Rounds 1-5	0.0547	0.1945	0.0780
Rounds 6-10	0.0605	0.2350	0.0980
Total	0.0576	0.2148	0.0880
	without/with	with/audits	without/audits
Significance	$p < 0.001^{***}$	$p < 0.001^{***}$	$p = 0.065^{*}$

Panel 3: Mean relative misrepresentation (Δ_{rel})

Rounds 1-5	0.1604	0.4643	0.1910
Rounds 6-10	0.1683	0.6057	0.2152
Total	0.1644	0.5350	0.2031
	without/with	with/audits	without/audits
Significance	$p < 0.001^{***}$	$p < 0.001^{***}$	$p = 0.660$

Table 3: Descriptive statistics of the Groves treatments. Mann-Whitney U-tests, unit of observation: individual averages across rounds. ***, ** and * signifies significance at the 1%-, 5%- and 10%-level.

Panel 1 (Groves treatment with communication): Messages about the productivity parameters during the communication phase

Round	1	2	3	4	5	6	7	8	9	10	Total
Understatements	0	1	0	1	2	0	1	1	2	1	9
	(0%)	(3.70%)	(0%)	(3.70%)	(7.14%)	(0%)	(3.33%)	(3.33%)	(6.897%)	(3.45%)	(3.321%)
Truthful reports	18	25	24	26	26	28	29	29	26	28	259
	(100%)	(92.60%)	(96%)	(96.30%)	(92.86%)	(100%)	(96.67%)	(96.67%)	(89.655%)	(96.55%)	(95.572%)
Overstatements	0	1	1	0	0	0	0	0	1	0	3
	(0%)	(3.70%)	(4%)	(0%)	(0%)	(0%)	(0%)	(0%)	(3.448%)	(0%)	(1.107%)
Number of messages	18	27	25	27	28	28	30	30	29	29	271
	(100%)	(100%)	(100%)	(100%)	(100%)	(100%)	(100%)	(100%)	(100%)	(100%)	(100%)

Panel 2 (Groves treatment with communication): Behavior after agreement upon deviations from truth telling

Round	1	2	3	4	5	6	7	8	9	10	Total
Reports according to	13	22	22	25	27	29	27	21	27	23	236
agreement	(92.86%)	(95.65%)	(95.65%)	(100%)	(100%)	(96.67%)	(90.00%)	(95.45%)	(96.43%)	(95.83%)	(95.55%)
Deviations	1	1	2	0	0	1	3	1	1	1	11
	(7.14%)	(4.35%)	(8.33%)	(0%)	(0%)	(3.33%)	(10.00%)	(4.55%)	(3.57%)	(4.17%)	(4.45%)
Number of agreements	14	23	24	25	27	30	30	22	28	24	247
	(100%)	(100%)	(100%)	(100%)	(100%)	(100%)	(100%)	(100%)	(100%)	(100%)	(100%)

Panel 3 (Groves treatment with communication and audits): Behavior after agreement upon deviations from truth telling

Round	1	2	3	4	5	6	7	8	9	10	Total
Reports according to	4	10	20	7	17	10	16	14	9	12	119
agreement	(100%)	(100%)	(100%)	(100%)	(89.47%)	(90.91%)	(100%)	(93.33%)	(81.82%)	(92.31%)	(94.44%)
Deviations	0	0	0	0	2	1	0	1	2	1	7
	(0%)	(0%)	(0%)	(0%)	(10.53%)	(9.09%)	(0%)	(6.67%)	(18.18%)	(7.67%)	(5.56%)
Number of agreements	4	10	20	7	19	11	16	15	11	13	126
	(100%)	(100%)	(100%)	(100%)	(100%)	(100%)	(100%)	(100%)	(100%)	(100%)	(100%)

Table 4: Analysis of the communication in the Groves treatments with communication.

		without communication	with communication
Overstatement	Δ_{abs}	0.1700	0.2250
	Δ_{rel}	0.4180	0.5787
Truthful report	Δ_{abs}	0.0667	0.2210
	Δ_{rel}	0.2050	0.5324
Understatement	Δ_{abs}	-0.0289	0.1700
	Δ_{rel}	-0.0848	0.4416

Table 5: Mean absolute and relative misrepresentation in the Groves treatments with and without communication contingent on the answer to the following question of the questionnaire: "If you only played once with your partner and you already knew his decision, it would always be beneficial for you to (a) report a productivity higher than your actual productivity, (b) report your actual productivity, (c) report a productivity lower than your actual productivity."

Panel 1: Number of reports

	without communication	with communication
Understatements	77 (19.25%)	32 (8.00%)
Truthful reports	195 (48.75%)	293 (73.25%)
Overstatements	128 (32.00%)	75 (18.75%)
Total	400 (100%)	400 (100%)

Panel 2: Mean absolute misrepresentation (Δ_{abs})

Rounds 1-5	0.0310	0.0315
Rounds 6-10	0.0365	0.0335
Total	0.0338	0.0325
	without/with	
Significance	$p = 0.348$	

Panel 3: Mean relative misrepresentation (Δ_{rel})

Rounds 1-5	0.0619	0.0374
Rounds 6-10	0.0924	0.0834
Total	0.0772	0.0604
	without/with	
Significance	$p = 0.934$	

Table 6: Descriptive statistics of the profit sharing treatments. Mann-Whitney U-tests, unit of observation: individual averages across rounds. ***, ** and * signifies significance at the 1%-, 5%- and 10%-level.

Panel 1: Profit sharing without communication

	Equilibria with $\delta_i = \delta_j = 0$	Equilibria with $\delta_i = \delta_j = \pm 0.1$
Rounds 1-5	5.2	0.8
	(26%)	(4%)
Rounds 6-10	4.8	1.2
	(24%)	(6%)
Total	5	1
	(25%)	(5%)

Panel 2: Profit sharing with communication

	Equilibria with $\delta_i = \delta_j = 0$	Equilibria with $\delta_i = \delta_j \neq 0$
Rounds 1-5	11.2	0.8
	(56%)	(4%)
Rounds 6-10	12.2	1
	(61%)	(5%)
Total	11.7	0.9
	(58.5%)	(4.5%)

Table 7: Ex post equilibrium play in both profit sharing treatments: Average number of pairs per round hitting an equilibrium.

		Profit sharing without comm. $\Delta_{rel} = 0.0722$	Profit sharing with comm. $\Delta_{rel} = 0.0602$
Groves without comm.	$\Delta_{rel} = 0.1643$	$p = 0.090^{*}$	$p = 0.043^{**}$
Groves with comm.	$\Delta_{rel} = 0.5350$	$p < 0.001^{***}$	$p < 0.001^{***}$
Groves with comm. and audits	$\Delta_{rel} = 0.2031$	$p = 0.002^{***}$	$p < 0.001^{***}$

Table 8: Mean relative misrepresentation in all treatments. Mann-Whitney U-tests, unit of observation: individual averages across rounds. ***, ** and * signifies significance at the 1%-, 5%- and 10%-level.

	Profit sharing without comm.	Profit sharing with comm.	Groves without comm.	Groves with comm.	Groves with comm. and audits
Rounds 1-5	1.39	0.75	3.17	3.76	1.94
Rounds 6-10	1.12	0.51	2.88	4.54	2.13
Total Mean	1.26	0.63	3.03	4.15	2.04
Median	1.28	0.00	1.82	4.15	1.52
PS without comm.		$p = 0.007^{***}$	$p = 0.152$	$p < 0.001^{***}$	$p = 0.372$
PS with comm.			$p = 0.001^{***}$	$p < 0.001^{***}$	$p = 0.017^{**}$
Groves without comm.				$p = 0.020^{**}$	$p = 0.440$
Groves with comm.					$p = 0.002^{***}$

Table 9: Mean and median efficiency losses due to deviations from truth telling. Mann-Whitney U-tests, unit of observation: efficiency loss of each pair averaged across rounds. ***, ** and * signifies significance at the 1%-, 5%- and 10%-level.